1.4 Bohr's Model of an Atom

Between 1913 and 1915 Niels Bohr developed a quantitative atomic model for the Hydrogen atom that could account for its spectrum. The model incorporated the nuclear model of the atom proposed by Ruthorford on the basis of his experiments. We shall see that this model was successful in its ability to predict the gross features of the spectrum emitted by Hydrogen atom. This model was developed specifically for Hydrogenic atoms. Hydrogenic atoms are those which consist of a nucleus with positive charge + Ze (Z = atomic number, e = charge of electron) and a single electron. More complex electron-electron interactions in an atom are not accounted in the Bohr's Model that's why it was valid only for one electron system or hydrogenic atoms.

The Bohr model is appropriate for one electron systems like H, He^{+}, Li^{+2} etc. and it was successful upto some extent in explaining the features of the spectrum emitted by such hydrogenic atoms. However this model is not giving a true picture of even these simple atoms. The true picture is fully a quantum mechanical affair which is different from Bohr model in several fundamental ways. Since Bohr model incorporates aspects of some classical and some modern physics, it is now called semiclassical model. Bohr has explained his atomic model in three steps called postulates of Bohr's atomic model. Lets discuss these postulates one by one.

1.4.1 First Postulate

In this postulate Bohr incorporates and analyze features of the Ruthorford nuclear model of atom. In this postulate it was taken that as the mass of nucleus is so much greater then the mass of electron, nucleus was assumed to be at rest and electron revolves around the nucleus in an orbit. The orbit of electron is assumed to be circular for simplicity. Now the statement of first postulate is "*During revolution of electron around the nucleus in circular orbit, the electric coulombian force on electron is balanced by the centrifugal force acting on it in the rotating frame of reference.*"

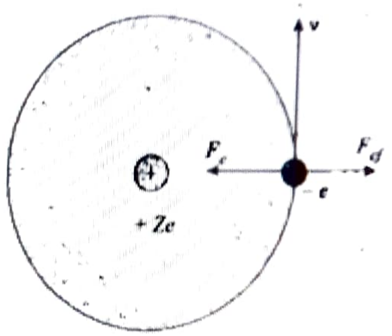


Figure 1.5

If electron revolves with speed v in the orbit of radius r. Then relative to rotating frame attached with electron, the centrifugal force acting on it is

$$F_{cf} = \frac{mv^2}{r} \qquad ...(1.1)$$

The coulombian force acting on electron due to charge of nucleus (+ Ze) is

$$F_{electric} = \frac{K(e)(Ze)}{r^2}$$

$$\Rightarrow \qquad = \frac{KZe^2}{r^2} \qquad ...(1.2)$$

Now according to first postulate from equation-(1.1) & (1.2) we have

$$\frac{mv^2}{r} = \frac{KZe^2}{r^2}$$

$$\Rightarrow \qquad mv^2 = \frac{KZe^2}{r} \qquad ...(1.3)$$

Equation-(1.3) is called equation of Bohr's first postulate.

1.4.2 Second Postulate

In the study of atom, Bohr found that while revolving around the nucleus the orbital angular momentum of the electron was restricted to only certain values, we say that the orbital angular momentum of the electron is quantized. He therefore took this as a second postulate of the model. The statement of second Postulate is, Bohr proposed that - "*During revolution around the nucleus, the orbital angular momentum of electron L could not have just any value, it can take up only those values which are integral multiples of Plank's Constant divided by 2π* i.e. $\frac{h}{2\pi}$"

Thus the angular momentum of electron can be written as

$$L = \frac{nh}{2\pi} \qquad ...(1.4)$$

Where n is a positive integer, known as quantum number. In an orbit of radius r if an electron (mass m) revolves at speed v, then its angular momentum can be given as

$$L = mvr \qquad ...(1.5)$$

Now from equation-(1.4) and (1.5), we have for a revolving electron

$$mvr = \frac{nh}{2\pi} \qquad ...(1.6)$$

Equation-(1.6) is known as equation of second postulate of Bohr model. Here the quantity $\frac{h}{2\pi}$ occurs so frequently in modern physics that, for convenience, it is given its own designation $\hbar$, pronounced as "h-bar."

$$\hbar = \frac{h}{2\pi} \simeq 1.055 \times 10^{-34} \text{ J-s} \qquad ...(1.7)$$

1.4.3 Third Postulate

While revolution of an electron in an orbit its total energy is taken as sum of its kinetic and electric potential energy due to the interaction with nucleus. Potential energy of electron revolving in an orbit of radius r can be simply given as

$$U = -\frac{K(e)(Ze)}{r}$$

$$\Rightarrow \qquad U = -\frac{KZe^2}{r} \qquad ...(1.8)$$

For kinetic energy of electron, we assume that relativistic speeds are not involved so we can use the classical expression for kinetic energy. Thus kinetic energy of electron in an orbit revolving at speed v can be given as

$$K = \frac{1}{2}mv^2 \qquad ...(1.9)$$

Thus total energy of electron can be given as

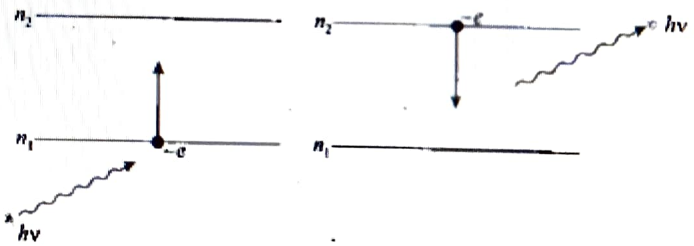
$$E = K + U = \frac{1}{2}mv^2 - \frac{KZe^2}{r} \quad ...(1.10)$$

Here we can see that while revolving in a stable orbit, the energy of electron remains constant. From the purely classical viewpoint, during circular motion, as electron is accelerated, it should steadily loose energy by emitting electromagnetic radiations and it spiraled down into the nucleus and collapse the atom.

Bohr in his third postulate stated that "*While revolving around the nucleus in an orbit, it is in stable state, it does not emit any energy radiation during revolution. It emits energy radiation only when it makes a transition from higher energy level (upper orbit) to a lower energy level (lower orbit) and the energy of emitted radiation is equal to the difference in energies of electron in the two corresponding orbits in transition.*"

If an electron makes a transition form a higher orbit n_2 to a lower orbit n_1 as shown in figure-1.69 (b). Then the electron radiates a single photon of energy

$$\Delta E = E_{n_2} - E_{n_1} = h\nu$$



(a) (b)

Figure 1.6

Here E_{n_2} and E_{n_1} are the total energies of electron in the two orbits n_2 and n_1. The emitted photon energy can be expressed as $h\nu$ where ν is the frequency of radiated energy photon. If λ be the wavelength of photon emitted then the energy of emitted photon can also be given as

$$\Delta E = h\nu = \frac{hc}{\lambda} \quad ...(1.11)$$

Similarly when energy is supplied to the atom by an external source then the electron will make a transition from lower energy level to a higher energy level as shown in figure-1.6 (a). This process is called excitation of electron from lower to higher energy level. In this process the way in which energy is supplied to the electron is very important because the behaviour of the electron in the excitation depends on the process by which energy is supplied from an external source. This we'll discuss in detail in later part of this chapter.

First we'll study the basic properties of an electron revolving around the nucleus of hydrogenic atoms.